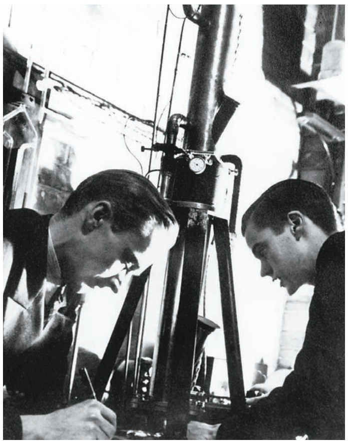
CANADIANS IN PHYSICS

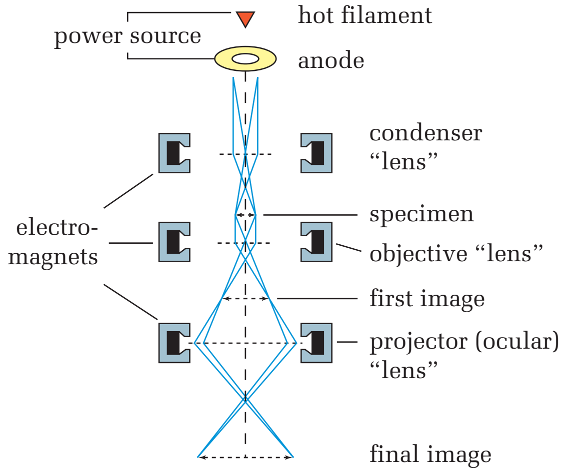
University of Toronto Graduate Students Make History

Although many research groups around the world were attempting to design and build electron microscopes in the 1930s, the first high-resolution electron microscope that was practical and therefore became the prototype for the first commercial instrument was designed, built, and tested by two graduate students at the University of Toronto. James Hillier and Albert Prebus are shown in the photograph with the electron microscope that they built in 1938. Hillier continued to perfect and use the electron microscope while he completed his Ph.D. degree. In 1940, Hillier joined the staff of the Radio Corporation of America (RCA) in Camden, New Jersey, where he continued to improve the electron microscope. In 1969, Hillier became the executive vice president in charge of research and engineering for RCA. In this position, he was responsible for all of the research, development, and engineering programs.



The race to build electron microscopes was based on Davisson and Germer's verification of the wave properties of electrons. Electron microscopes have much greater resolving power than light microscopes, due to their very short wavelengths. Resolving power is the ability to distinguish two or more objects as separate entities, rather than as one large object. If the distance between two objects is much less than the wavelength, a microscope "sees" them as one particle, rather than as two. You can magnify the image to any size, but all that you will see is one large, blurred object. Since the shortest wavelength of visible light is about 400 nm and electrons can have wavelengths of 0.005 nm, electron microscopes could theoretically have a resolving power more than 10 000 times greater than light microscopes. In practice, however, electron microscopes have resolving powers about 1000 times greater than light microscopes.

The diagram shows the typical design of a transmission electron microscope. The barrel of the microscope must be evacuated, because electrons would be scattered by molecules in the air. Electrons would not penetrate glass lenses, of course, so focussing is accomplished by magnetic fields created by electromagnets. These magnetic "lenses" do not have to be moved or changed, because their focal lengths can be changed simply by adjusting the magnetic field strength of the electromagnets. Since electrons cannot penetrate glass, the extremely thin electron microscope specimens are placed on a wire mesh so that the electrons can penetrate the areas between the tiny wires.



The photograph at the beginning of this chapter was produced by a scanning electron microscope. These instruments function on a very different principle than do transmission electron microscopes. A very tiny beam of electrons sweeps back and forth across the specimen, and electrons that bounce back up from the sample are detected. Scanning electron microscopes were first developed in 1942, but they were not commercially available until 1965.

WEB LINK

www.mcgrawhill.ca/links/physics12

For more information about Hillier and Prebus and the history of the electron microscope, including diagrams and photographs, go to the above Internet site and click on **Web Links**.

The Wave-Particle Duality

Within 30 years after Planck presented his revolutionary theory to the German Physical Society, physicists had come to accept the particle nature of light and the wave nature of subatomic particles. They did not, however, forsake Maxwellian electromagnetism or Newtonian mechanics. Newton's concepts have made it possible for astronauts to travel to the Moon and back and to put satellites into orbit. Maxwell's electromagnetism permits engineers to develop the technology to send microwaves to and from these satellites. Physicists accept the dual nature of radiant energy that propagates through space as waves and interacts with matter as particles or discrete packets of energy.

Matter also has a dual nature, but only the subatomic particles have a small enough mass, and thus a large enough wavelength, to exhibit their wave nature. In 1924, Albert Einstein wrote, "There are therefore now two theories of light, both indispensable, and — as one must admit today despite twenty years of tremendous effort on the part of theoretical physicists — without any logical connection." Some physicists hope that in the future we will have a clearer picture of matter waves and quanta of energy. For now, we accept the **wave-particle duality:** Both matter and electromagnetic energy exhibit some properties of waves and some properties of particles.

12.2 Section Review

1. C Explain how Compton determined the momentum of a photon — a particle that has no mass.
2. C Describe the Compton effect.
3. K/U What was the most important result of Compton's experiments with the collisions between photons and electrons?
4. K/U Compton was able to ignore the work function of the metal in which the electrons were embedded in his momentum calculations. How was he able to justify this?
5. C Describe the reasoning that de Broglie used to come up with the idea that matter might have wave properties.
6. C When you walk through a doorway, you represent a particle having momentum and, therefore, having a wavelength. Why is it improbable that you will be "diffracted" as you pass through the doorway?
7. K/U Attempts to demonstrate the existence of de Broglie matter waves by using a beam of electrons incident on Young's double-slit apparatus proved unsuccessful. Give one possible explanation.
8. C Explain the technique that Davisson, Germer, and George P. Thomson used to verify the wave nature of electrons.
9. MC Research the production of X rays and prepare a display poster. In your display, include a diagram of the general structure of the X-ray tube, an explanation of how electrons cause the production of X rays, and an indication of the societal importance of the technology.